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Freshwater seepage along the coast of the western Dampier Peninsula, Kimberley region, Western Australia

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Abstract

Controlled by the stratigraphic relationships along the shore of the western Dampier Peninsula, there are several mechanisms that deliver freshwater of the hinterland to the shore zone. These include seepage along the edge of the red sand dunes, rivulets discharging into tidal embayments, impounding of rivulets and streams by dunes, and freshwater discharges onto the low tidal zone from the subsurface. These freshwater sources, known as springs, jila (permanent water source) or soaks, are of great cultural value to the Yawuru and other indigenous groups of the Dampier Peninsula. Two of the most interesting are those that illustrate seepage of freshwater into the muddy upper shore zone and the interaction of hinterland groundwater and tidal flat carbonate mud, viz., the seepage lines at the edge of the "pindan" terrain where it borders the mud of tidal flats resulting in linear *Melaleuca* thickets fringing the "pindan", and the headwaters of scalloped embayments where rivulets discharge surface and groundwater onto/into the tidal flat forming a complex of wetland vegetation. Areas of marked freshwater seepage along the interface of the hinterland and the carbonate mud tidal flats can also be zone of dissolution, resulting in solutional-excavation of the muds and the development of wetland basins.

Keywords: Kimberley Coast, Dampier Peninsula, tropical, coastal wetlands, freshwater seepage

Introduction

Freshwater seepage and freshwater run-off into the coastal zone has important implications for coastal ecology (Semeniuk 1983; Cresswell 2000) and for thousands of years have provided freshwater to the indigenous groups such as the Yawuru, Ngumabal and Jabirrjabirr who inhabited the west coast of the Dampier Peninsula. The springs, freshwater seepages and permanent wetlands, such as Nimalarragan has provided rich biodiversity for these groups. Depending on the climate setting (rainfall), and appropriate aquifers of the hinterland and how they deliver freshwater to the coastal zone, shoreline seepage and surface freshwater inflow can be of low volume, or be quite marked.

The Dampier Peninsula, in the western Kimberley region, residing in a tropical semi-arid monsoon climate has a unique system of freshwater seepage and efflux zones along its western margins. In a shore environment wherein there are tidal flat sediments, salt flats, mangrove formations, and coastal dunes, freshwater is delivered as a surface flow and as subsurface seepages. Interacting with the shoreline deposits, such as dunes and tidal mud, it has generated lagoons and wetlands, and fringing paperbark swamps, respectively.

To date, the styles of freshwater seepage and freshwater inflow have not been described. In particular the significance of the effect of tidal flat muds hydrogeologically on discharge of freshwater from hinterland aquifers into the marine environments has not been described, but it is an important hydrological feature of the shore leading to the development of specific coastal wetlands.

This paper is an account of freshwater seepages and surfaces flow into the shore zone of the western Dampier Peninsula (or Dampier Land) outlining the geological and stratigraphic framework underpinning freshwater seepages, the types of wetlands and environments produces, and the biological response.

Regional setting

Critical to the understanding of the freshwater seepage and freshwater delivery into the shore zone of the western Dampier Peninsula is the geological framework of the Peninsula, its geomorphology, stratigraphy, climate, and hydrology.

The Dampier Peninsula is a north-trending regional-scale landform whose core is Mesozoic rock (mainly Broome Sandstone) mantled by weathered Broome Sandstone and Quaternary red sand (Brunnschweiler 1957; Geological Survey of Western Australia 1975; Gibson 1983a, 1983b; Gozzard 1988; Fig. 1). The Peninsula is some 170–230 m above sea level along its north to NNW-trending central axis, with elevation decreasing to 20–40 m to north, west, and east towards the coast. The geomorphology of the Peninsula consists of sand plains and linear dunes (often termed "pindan" to refer to the red sand and vegetation complex of this surface) that are dissected by low-gradient, low-relief

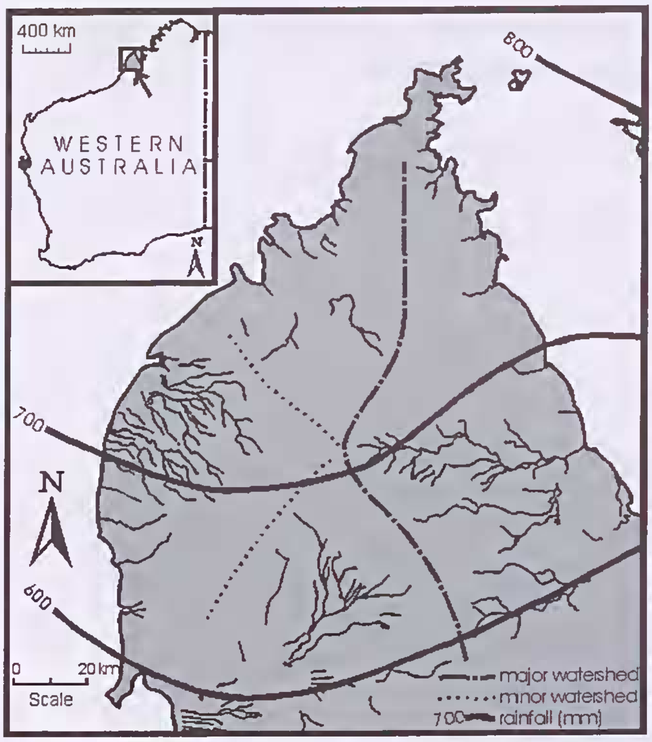

Figure 1. Location of the Dampier Peninsula, showing rainfall isohyets, major and minor watersheds, and main drainage lines that lead to the coast.

streams that have incised through the dune sediments and locally expose Mesozoic rock in their valley tracts. The western coastal zone of the Peninsula consists of mud-filled scalloped embayments, rocky shores cut into Broome Sandstone, shores cut into the red sand, ribbons of coastal dunes, coastal dune and leeward lagoons, coastal dune barriers and leeward mud-filled embayments, shore-parallel limestone, and ribbons of beach rock ramps. Rivulets traversing the Peninsula debouch into the headwaters of the scalloped embayments, or empty into lagoons barred by small barriers, or discharge into the ocean through a (semi-barred) curved outlet.

The stratigraphy of the Dampier Peninsula consists of mainly Broome Sandstone that is overlain by a thin pisolitic to massive ironstone, and a cover of red sand (the Mowanjum Sand; Semeniuk 1980). In the embayments along its west coast there is tidal flat carbonate mud (Sandfire Calcilutite; Semeniuk 2008) which interfingers and grades into the red sand in a zone of muddy sand (Djugun Member; Semeniuk 2008). Also along the coast, abutting or overlying the Broome Sandstone, or cliffs cut into Mowanjum Sand are local outcrops of Pleistocene limestone, shoestrings of Holocene limestone (the Horsewater Soak Calcarenite, Kennedys Cottage Limestone and Willie Creek Calcarenite; Semeniuk 2008), ribbons and shoestrings of beach and dune sand (Cable Beach Sand and Shoonta Hill Sand, respectively; Semeniuk 2008). These stratigraphic relationships are shown in Figure 2.

The climate of the Dampier Peninsula is tropical semi-arid. Rainfall shows a north to south decrease with ~ 800 mm at Cape Leveque and 600 mm at Broome (Fig. 1). The rain is highly seasonal, precipitating in the summer months (Gentilli 1972; Bureau of Meteorology 1973, 1975, 1988).

The rocks and sediments that comprise the Dampier Peninsula function as aquifers to a range of water bodies. Freshwater resides in the Broome Sandstone (Laws 1990, 1991), with a water table near sea level at the coast and rising inland to form a groundwater mound under the Peninsula (Laws 1990, 1991). At the coast and extending several kilometres inland, the freshwater in the Broome sandstone is underlain by salt water (Laws 1991), the Ghyben-Herzberg interface (Davis & DeWiest 1966). Freshwater also resides in the coastal limestones, and the coastal dunes and, depending on the stratigraphic setting (*e.g.*, the latter is underlain by Sandfire Calcilutite, a whitish calcareous mud known to the Traditional Owners as "kalji"), they may be contiguous with or separate from the regional groundwater residing in the Broome Sandstone. The Mowanjum Sand also stores fresh water that is generally contiguous with the regional groundwater. Salt water resides in the beach sands. As a formation, it is generally near MSL in near-coastal settings and, as such, the aquifer stores freshwater along the dune / tidal flat interface. Salt water, with salinities up to hypersaline, resides in the carbonate mud deposits of the Sandfire Calcilutite within the interval of the formation occurring between mean sea level (MSL) and equinoctial high water spring tide (EHWS). The Sandfire Calcilutite, at its landward occurrences, generally also is a stranded deposit, having formed during a time of higher Holocene MSL (~ 2 m above present MSL), and locally it is weakly (diagenetically) indurated (Semeniuk 2008). These latter aspects of the Sandfire Calcilutite contribute to its impeding freshwater discharge into the coastal zone (see later).

Run-off from the drainage basins on the Peninsula is channelled into a series of streamlines (Fig. 1) and discharges to the coast. However, depending on the nature of the topography of Broome Sandstone and weathered Broome Sandstone where they are buried under the Mowanjum Sand, some channels are open for surface water flows, and some function as buried channels (conduits) for subsurface flows.

Freshwater discharges in the coastal zone

There are range of freshwater discharges in the coastal zone (Fig. 2). There include linear seepage along the edge of the red sand dunes, lakes and soaks at the mouth of rivulets, dune-barred streams forming lakes and sumplands, linear dune seepage onto high tidal zone, and freshwater discharges onto the low tidal zone from the subsurface.

Freshwater in the red sand dunes discharges to seawards, and in a stratigraphic context of carbonate mud onlapping the sand, freshwater flow is impeded by the barrier of relatively impermeable mud (the Sandfire Calcilutite), and discharges to the surface as a spring (Fig. 3A), particularly where the calcilutite is a Holocene stranded deposit, and/or is weakly indurated. The freshwater discharge thus occurs along the contact of the red sand dunes (the "pindan") and high-tidal carbonate mud flats in a linear interface (Fig. 3A) following the

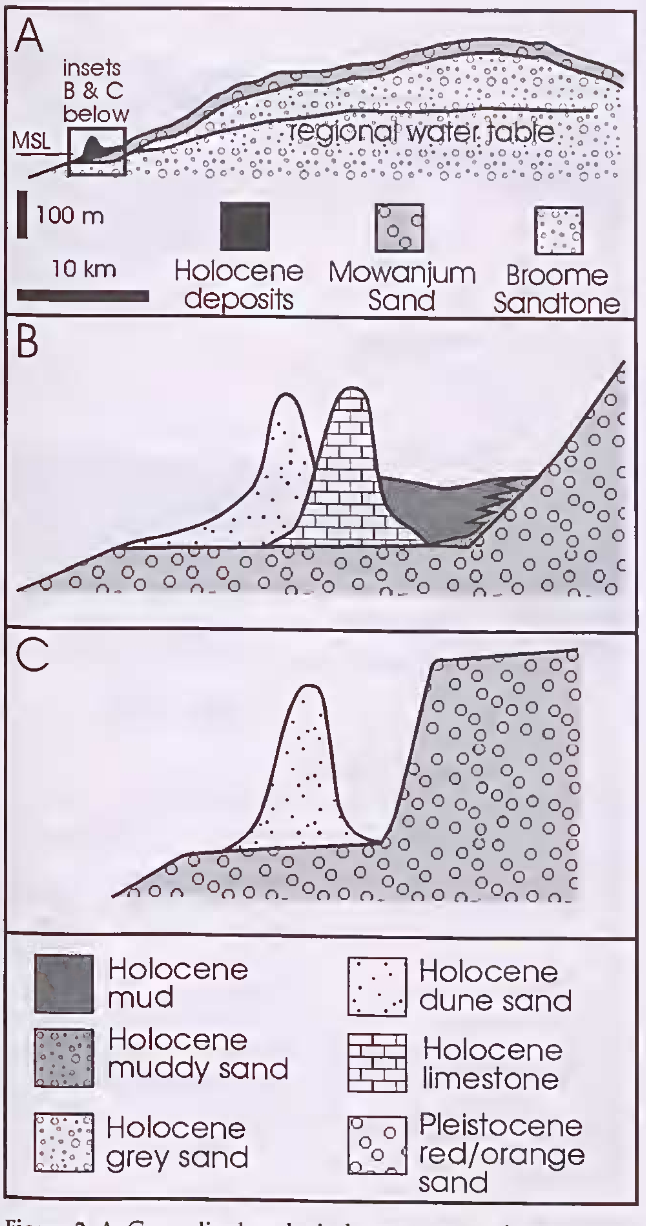

Figure 2. A. Generalised geological cross-section of the Dampier Peninsula showing a base rock of Mesozoic rock and a veneer of Pleistocene Mowanjum Sand (modified after Laws 1990, 1991; Semeniuk 2008). B. Stratigraphic cross-section of a coastal zone where Holocene sand and Holocene limestone bar an embayment filling with Sandfire Calcilutite (modified after Semeniuk 2008). The Holocene units overlie and abut the Pleistocene Mowanjum Sand. C. Stratigraphic cross-section of a coastal zone where Holocene dune sand abuts the Pleistocene Mowanjum Sand (modified after Semeniuk 2008).

edge of the "pindan". Seepage is facilitated by the muddy sand transition between red sand of the dune fields and carbonate mud ("kalji") of the tidal flats. Along the interface, the freshwater of the groundwater under the dunes field grades to brackish water under the zone of seepage to hypersaline under the high-tidal parts of the mud flat (Fig. 3B). The vegetation that inhabits this seepage zone consists of *Melaleuca* thickets and forests (mainly *Melaleuca acaciodes*), and locally high-tidal mangroves (*Avicennia marina*). In areas of marked seepage, carbonate muds along the interface are dissolved and solutionally-excavated, forming a more permanent (linear) wetland body.

Freshwater in the red sand dunes also discharges to seawards along its contact with coastal dunes. The freshwater discharge occurs along the contact of the red sand dunes and the dunes forming a series of wetland in the swale or depression between the red sand and the coastal dunes. The vegetation that inhabits this seepage zone consists of *Melaleuca* thickets and forests and locally vine thickets.

Rivulets that debouch into headwater of the carbonate-mud-filled scalloped embayments also create zones of wetlands, i.e., lakes and soaks at the mouth of rivulets (Fig. 3C). In these settings, the rivulets have delivered quartzose sand and kaolinitic mud to triangular to fan-shaped high-tidal alluvial fan deposits that interfinger with carbonate mud of the high-tidal flat (Fig. 3C). The freshwater discharge occurs along the rivulet as surface flow during the monsoon season, and as base flow during the dry winter. The flow is impeded by the carbonate mud of the high-tidal flat and surfaces as a spring that is expressed as a permanently waterlogged area (a dampland to sumpland, locally known as a soak), or a lake. The wetland thus formed tends to be, in plan, triangular in shape. Seepage is facilitated by the muddy sand transition between red sand of the dune field, the high-tidal alluvial fan, and the carbonate mud of the tidal flats. Along the interface, the freshwater of the groundwater under the dune field and in the high-tidal alluvial fan grades to brackish water under the zone of seepage to hypersaline under the high-tidal parts of the mud flat (Fig. 3D). The vegetation that inhabits this seepage zone consists of *Melaleuca* thickets and forests (*Melaleuca accacioides, Melaleuca cajuputi*), *Pandanus spiralis* associations, and rushlands and sedgelands (with *Schoenoplectus litoralis*), the evergreen tree *Timonius timon*, local Dragon Trees (*Sesbania formosa*), and also, locally, mangrove (*Lumnitzera racemosa*). Similar to the linear seepage zone, in areas of marked discharge, the carbonate muds in the path of the freshwater are dissolved (solutionally-excavated), forming a more permanent (oval to triangular) wetland body.

Streams and rivulets that discharge to the sea have their mouth barred by sand accumulations formed initially by longshore drift, and further barred by coastal dune development (Fig. 3E). These are the dune-barred streams forming impounded lagoons that are lakes and sumplands (Fig. 3F); wetland classification after Semeniuk & Semeniuk 1995. They tend to contain permanent water in the leeward lagoon. The shapes of the water bodies follows the shape of the channel, i.e., they are linear to curvilinear because where the channel has attempted top breach the barrier, the channel has been deflected or curved. Where vegetated, the lagoons support *Melaleuca* thickets and forests, *Pandanus* associations, and rushlands and sedgeland.

The linear dunes of red sand also discharge freshwater under the tidal flats. Fingers of sand, as water-bearing aquifers, lie buried under mud tidal flat, and can convey freshwater to under hypersaline tidal flats. These zones of freshwater discharge remain as subsurface phenomena, but ecologically their presence is manifest as brackish water ecosystems on a high-tidal flat. They are inhabited by *Avicennia marina*, or by copses of *Melaleuca* thickets, or by sedges. Discharge of freshwater into salt flats of eastern King Sound was described by Semeniuk

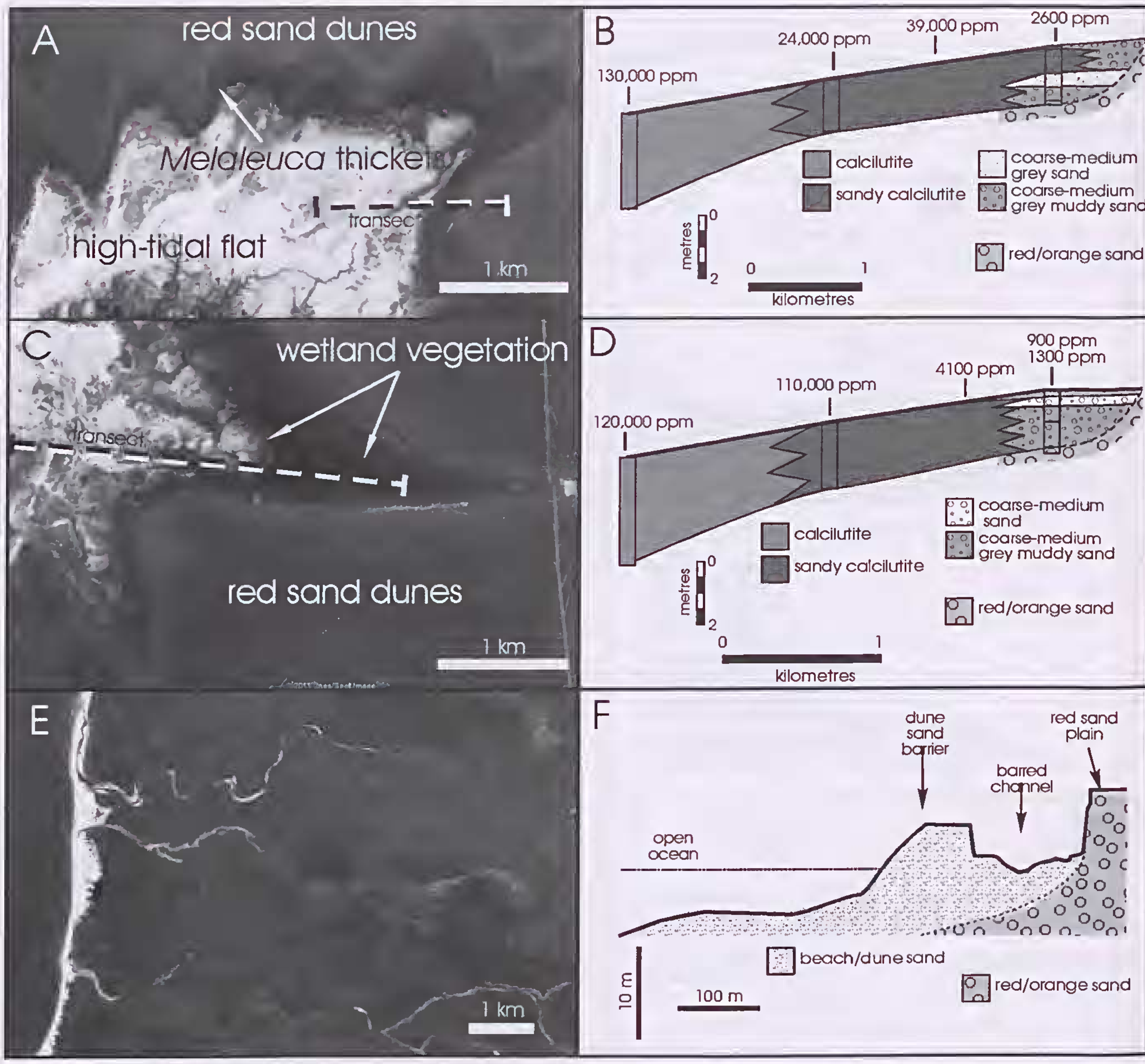

Figure 3. Three locations along the western coast of the Dampier Peninsula showing types of wetland and seepage zones. A. Willie Creek area showing red sand dune terrain, the tidal flats and the *Melaleuca fringe* developed along the zone of seepage. The transect for stratigraphy illustrated in (B) is shown. B. Stratigraphy and groundwater salinity along the transect. C. Willie Creek area showing red sand dune terrain, the tidal flats and the wetland vegetation developed along the contact between a rivulet and the tidal flat. The transect for stratigraphy illustrated in (D) is shown. D. Stratigraphy and groundwater salinity along the transect. E. West coast of Dampier Peninsula showing a range of rivulets (deriving from the terrain of red sand dunes) that are barred by the coastal sand dunes. F. Stratigraphy of area (E) in a transect normal to the coast.

(1980), and similar discharges from linear dunes and local rivulets forming high-tidal wetland, lakes and sumplands occur into the northeastern extremity of the Roebuck Plains, where stranded Quaternary tidal-flat mud adjoins and onlaps the red sand dunes. These locations of seepage are outside the area of study, but similar patterns to these occur along the western Dampier Peninsula.

Freshwater in limestones and in fractured Mesozoic sandstone can discharge onto the low tidal zone from the subsurface. Where there is outcrop of cavernous or microkarst limestone, or fractured sandstone on the low tidal zone (as a rocky shore platform), locally there can be developed springs of freshwater. These represent freshwater from the hinterland discharging along conduits in the aquifer from the subsurface onto the rocky shore zone.

A summary of the style of freshwater delivery to the coastal zone is provided in Figure 4.

Discussion

The freshwater discharges along the western coast of the Dampier Peninsula are significant from the perspective that these freshwater pockets and ecological

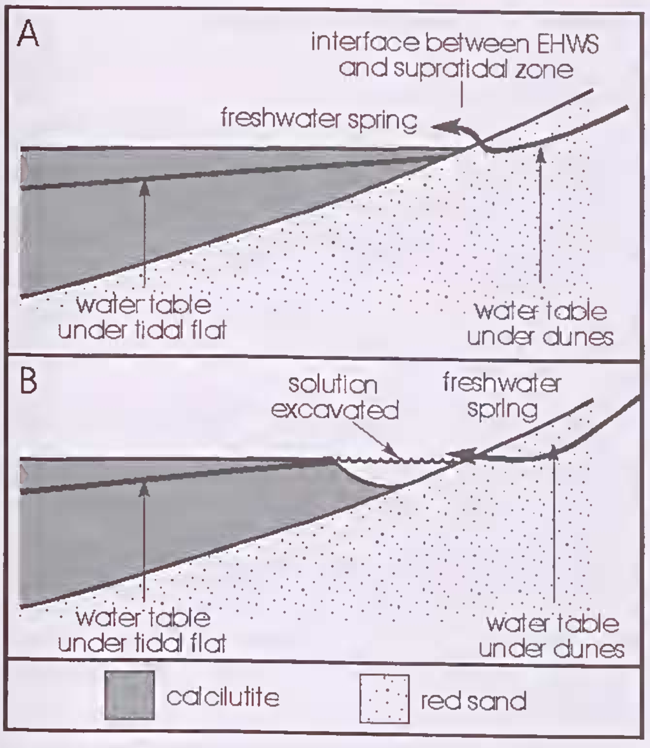

Figure 4. Mechanisms by which freshwater discharge from the red sand dunes forms springs and wetland zones along the contact of Mowanjum Sand and Sandfire Calcilutite. A. The Sandfire Calcilutite impedes freshwater discharge and forms freshwater springs. B. The Sandfire Calcilutite impedes freshwater discharge forming a freshwater spring which solution-excavates a wetland basin.

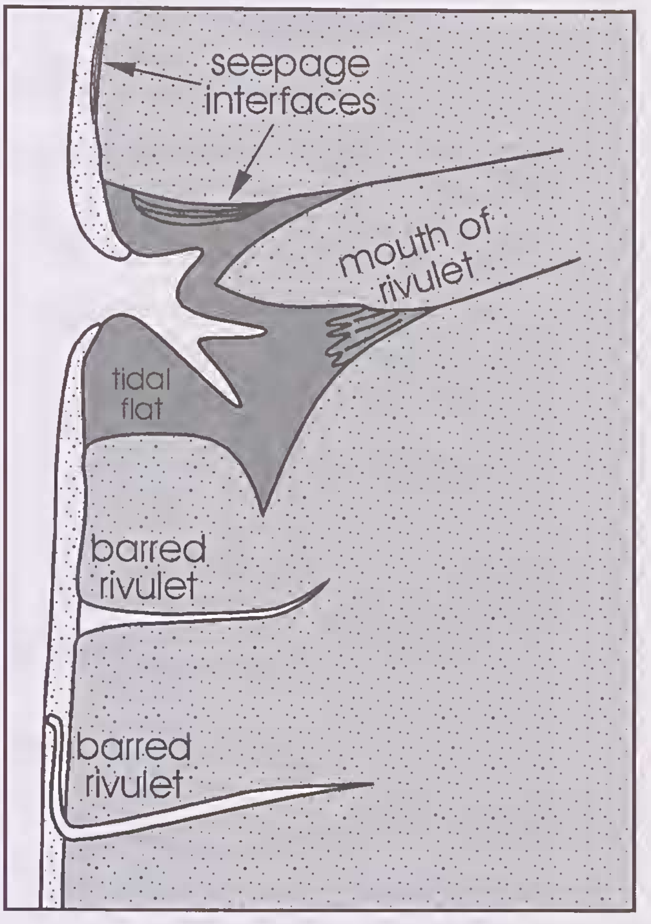

Figure 5. Types of wetlands formed along the coastal zone of the western Dampier Peninsula as a result of stratigraphic and hydrological interaction between the rivulets, Mowanjum Sand, the Sandfire Calcilutite ("kalji") and coastal dunes (Shoonta Hill Sand).

responses to the freshwater occurrences are in a regional setting of tropical semi-aridity. Locally, developed along this zone of freshwater discharge are vine thickets, and in fact the most southern occurrence of vine thickets in Western Australia is along the western Dampier Peninsula (Kenneally *et al.* 1996). Equivalent latitudes in Eastern Australia are humid with rainfall in excess of 1200 mm/pa and 1600 mm/pa, and further south of the Dampier Peninsula, the climate is too arid to support the vegetation and fauna that occurs along any zones of freshwater seepage. In this context, the freshwater seepages and their associated ecological products, particularly in this specific coastal stratigraphic and hydrolgical setting of red sand dunes and "kalji", are Nationally significant features.

A range of coastal wetlands are developed along the zone of freshwater seepage and the diversity is related to how freshwater is delivered to the coast, into what type of stratigraphic system the discharge takes place, and the characteristics of the stratigraphic units that may be impeding freshwater seepages. As a result there are linear zones of seepage along the edge of the red sand dunes, there are basin wetlands developed along the interface of coastal dunes and red sand dunes, and there are variously barred rivulets. The diagenetic interaction of a marked freshwater seepage zone and "kalji" is of particular interest. Here, solution excavation of the carbonate mud by freshwater results in a deeper basin and in a more permanently inundated wetland.

Various avifauna and other fauna use the wetland developed as freshwater seepages along the shore. The wetlands support a range of avifauna (Rubibi Working Group 1996) including the Purple Swamphen (*Porphyrio porphyrio*), the White-faced heron (*Egretta novahollandiae*), Brolga (*Grus rubicunda*), the Australiasian grebe (*Tachybaptus novahollandiae*), the Snipe (*Galinago* sp), and the Clamorous Reed-Warbler (*Acrocephalus stentoreus*), as well as visiting wading birds such as plovers, avocets, and sandpipers. The more permanent water bodies support freshwater herring (*Nematolosa erebi*), freshwater eel (*Anguilla bicolor*), and barramundi (*Lates calcarifera*).

The wetlands are clearly of National significance and require a careful management. Because of the various stratigraphic and physiographic settings, and the different maintenance mechamisms, the coastal wetlands along this seepage zone, in their variety of wetland expression and vegetation, require a variable management.

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